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Biomass and Nutrient Distributions in Central Oregon Second-Growth Ponderosa Pine Ecosystems

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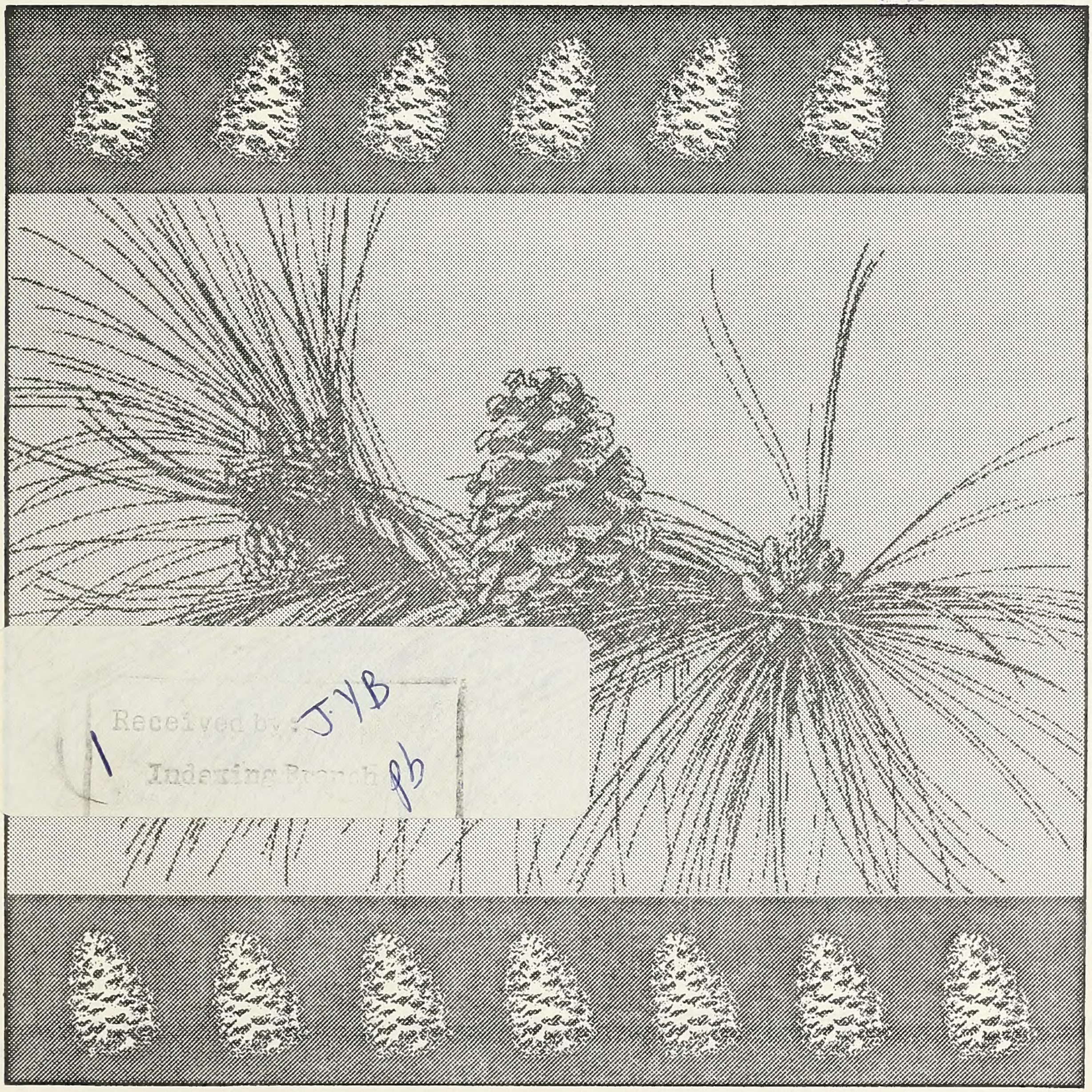

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Abstract

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We investigated the distribution of biomass and nutrients in second-growth ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) ecosystems in central Oregon. Destructive sampling of aboveground and belowground tree biomass was carried out at six sites in the Deschutes National Forest; three of these sites also were intensively sampled for biomass and nutrient concentrations of the soil, forest floor, residue, and shrub components. Tree biomass equations were developed that related component biomass to diameter at breast height and total tree height. No significant differences in equation coefficients were detected among sites, thereby allowing a pooling of the data for equations predicting dry weights for boles, crowns, bark, and coarse roots. Nutrient concentrations were highest in the foliage of trees and in the shrub component and lowest in the soil component. Total nutrient content, however, was greatest in the soil component. Assessment of the nutrient distributions suggests that bole-only harvesting and debarking onsite will result in the greatest retention of tree nutrients within the ecosystem.

Keywords: Biomass, nutrient concentrations, allometric equations, ponderosa pine, carbon storage.

Summary

This report describes the distribution of plant-related biomass, soil mass, and nutrients in second-growth ponderosa pine forest ecosystems in central Oregon. The stands sampled ranged in age from 45 to 100 years and were growing on areas of volcanic ash and pumice. Equations predicting tree biomass components from diameter at breast height and height revealed no significant site differences in tree allometry. Great variation in woody debris was observed, illustrating the patchy nature of the distribution of this important ecosystem component.

Few significant site differences were observed among nutrient concentrations in any of the measured ecosystem components. Nitrogen (N) concentrations were highest in the shrub component. In contrast, phosphorus (P) concentrations were highest in the soil. Of the tree components, crown and bark components had the highest concentrations of nitrogen and phosphorus.

On a per-hectare basis, the soil had the greatest contents of nutrients of all the ecosystem components because of its extreme mass. Of the tree components, bolewood contained the greatest total carbon, while the crown had the greatest total N and P. The distribution of the carbon in the various soil horizons differed notably from site to site, as did phosphorus and nitrogen contents. The importance of the forest floor as a nitrogen storage compartment is well demonstrated by the data presented here.

The ranges of dry weights provide some boundaries and averages for predicting ecosystem biomass and nutrient budgets. The nutrient contents reported here are static estimates of total nutrients, however, and do not necessarily represent those available to the trees. More intensive sampling of nutrients and their availability will provide a clearer picture of the impact of harvesting on nutrient export from the site. Although inflated nutrient contents in the soil appear to outweigh nutrient stores in the standing forest, absolute amounts of nutrients potentially leaving the site during harvest may be substantial. Bole-only harvesting is suggested if the high nutrient contents in the crown material are to be retained onsite.

Introduction

Extensive areas in eastern Oregon, California, and Washington support overstocked stands of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), mainly as a result of extensive railroad logging in the 1920s and fire suppression. These stands have a large buildup of forest floor material and woody debris. Foresters have been concerned about these forest conditions because of vulnerability to fire and insect damage. The Deschutes National Forest in central Oregon is entering into an accelerated program of intermediate harvests in second-growth ponderosa pine. Intermediate harvests to reduce the stocking in these areas also may reduce the fire hazard, improve the vigor of the remaining trees, and reduce vulnerability of the trees to the mountain pine beetle (*Dendroctonus ponderosae*) in particular. Interest in selective cutting to diversify stands also has emerged, because this type of management may reduce the probability of beetle infestation.

Limited quantitative information currently is available for estimating the amount and distribution of biomass needed to evaluate potential products, carbon storage, and fuel loadings in second-growth ponderosa pine on the east side of the Cascade Range. Land managers are in need of precise biomass estimates applicable to the ponderosa pine resource. In addition, potential impacts of product removal on the future productivity of the site must be explored.

This report presents estimators for biomass components of second-growth ponderosa pine populations sampled across six sites in the Deschutes National Forest. In addition, nutrient concentrations and contents were examined to quantify their distribution across key ecosystem components and speculate on potential impacts of product removal on site productivity.

Methods

Sites

Six sites were selected for determining tree biomass components and equations estimating them from more easily measured variables, such as height and diameter at breast height (d.b.h.). General characteristics of the six sites are provided in table 1. Three sites coincide with those chosen for a long-term study on the effects of intensive harvesting and slash treatment. The three groups of sites generally formed a gradient in site quality, with the two Sisters sites representing good to moderate growth conditions and the Fort Rock sites representing harsh conditions.

We defined our population as stands dominated by second-growth ponderosa pine, between the ages of 45 and 100 years, growing in areas of wind-deposited volcanic ash and pumice, and on level terrain (slopes less than 10 percent). Stands also had to have sufficient stocking to be considered in current timber management planning and to be entered for intermediate harvesting and site treatment within the next 20 years.

Site selections were made such that the sites were spread across the resource in geographical space, had large undisturbed tracts of stands, were accessible to logging equipment, and had no restrictions of conflicting environmental, cultural, or management goals.

Table 1—Average, standard deviation, and range of characteristics of sampled trees in ponderosa pine ecosystems in south-central Oregon on pumice soils

Site and component	Sample size	Mean	Standard deviation	Range Minimum	Range Maximum
Fort Rock 1:					
Tree measurement—					
Tree density (trees/ha)	438	—	—	—	—
Basal area (m^2/ha)	—	5018.28	—	—	—
D.b.h. (cm)	219	25.81	7.13	3.90	45.10
Height (m)	219	14.72	3.13	3.10	22.20
Weights (kg/tree)—					
Crown	219	64.33	39.07	.49	220.47
Bolewood (outside bark)	219	144.59	87.40	1.09	493.20
Bark	219	28.60	17.29	.22	97.57
Stump	10	43.83	29.25	4.70	109.64
Total aboveground dry weight		209.22	126.47	1.58	713.67
Roots	10	13.15	7.30	1.52	25.06
Total tree dry weight		255.65	152.64	2.22	859.02
Fort Rock 2:					
Tree measurement—					
Tree density (trees/ha)	286	—	—	—	—
Basal area (m^2/ha)	—	1988.42	—	—	—
D.b.h. (cm)	143	24.88	5.98	8.90	54.00
Height (m)	143	12.25	2.84	4.08	23.38
Weights (kg/tree)—					
Crown	143	65.46	45.26	3.52	416.78
Bolewood (outside bark)	143	98.39	68.03	5.29	626.46
Bark	143	20.76	14.40	1.12	132.19
Stump	10	26.66	13.28	3.37	46.72
Total aboveground dry weight	143	163.85	113.29	8.81	1043.24
Roots	10	14.90	15.70	1.42	53.33
Total tree dry weight	143	205.73	137.57	12.79	1260.05
Bend 1:					
Tree measurement—					
Tree density (trees/ha)	650	—	—	—	—
Basal area (m^2/ha)	—	10113.76	—	—	—
D.b.h. (cm)	325	24.69	8.95	3.00	51.60
Height (m)	325	16.23	4.30	1.90	26.40
Weights (kg/tree)—					
Crown	325	67.40	51.90	.21	285.04
Bolewood (outside bark)	325	159.36	120.80	.49	637.98
Stump	325	33.43	24.58	.28	143.35
Total aboveground dry weight	325	226.75	171.89	.70	959.02
Roots	325	11.50	8.90	.07	52.64
Total tree dry weight	325	271.64	205.11	1.06	1155.02

Table 1—Average, standard deviation, and range of characteristics of sampled trees in ponderosa pine ecosystems in south-central Oregon on pumice soils (continued)

Site and component	Sample size	Mean	Standard deviation	Range Minimum	Range Maximum
Bend 2:					
Tree measurement—					
Tree density (trees/ha)	278	—	—	—	—
Basal area (m^2/ha)	—	2875.43	—	—	—
D.b.h. (cm)	139	30.78	12.71	3.00	63.00
Height (m)	139	14.95	4.98	2.40	22.80
Weights (kg/tree)—					
Crown	139	111.42	81.65	.27	384.21
Bolewood (outside bark)	139	218.04	159.80	.52	751.89
Bark	139	39.30	28.80	.09	135.51
Stump	8	48.39	32.99	5.74	101.60
Total aboveground dry weight	139	329.46	241.45	.79	1136.10
Roots	8	23.56	32.81	1.17	100.18
Total tree dry weight	139	405.74	297.20	1.15	1441.41
Sisters 1:					
Tree measurement—					
Tree density (trees/ha)	522	—	—	—	—
Basal area (m^2/ha)	—	6668.71	—	—	—
D.b.h. (cm)	261	24.96	8.51	4.20	54.50
Height (m)	261	14.98	4.40	3.12	28.63
Weights (kg/tree)—					
Crown	261	49.50	39.62	.59	274.74
Bolewood (outside bark)	261	165.59	132.54	1.96	919.16
Bark	261	34.85	27.89	.41	193.42
Stump	261	33.69	24.74	.59	161.57
Total aboveground dry weight	261	215.09	172.16	2.54	1193.90
Roots	261	11.58	9.01	.16	59.72
Total tree dry weight	261	260.37	205.68	3.30	1415.20
Sisters 2:					
Tree measurement—					
Tree density (trees/ha)	444	—	—	—	—
Basal area (m^2/ha)	—	7052.99	—	—	—
D.b.h. (cm)	222	30.18	8.46	10.10	56.90
Height (m)	222	17.76	3.22	4.5	24.90
Weights (kg/tree)—					
Crown	222	63.92	40.92	2.38	236.13
Bolewood (outside bark)	222	259.32	166.01	9.67	957.98
Bark	222	55.35	35.44	2.06	204.48
Stump	222	48.89	30.50	4.04	77.54
Total aboveground dry weight	222	323.24	206.93	12.05	1194.11
Roots	222	17.10	11.28	1.22	65.97
Total tree dry weight	222	389.22	248.32	17.31	1437.63

— = all trees in a hectare were measured.

Tree Sampling

All trees in a 0.5-hectare plot at each site were measured for height and d.b.h. Sixteen trees in the dominant strata were randomly selected for biomass measurements and felled; one tree was sacrificed for testing and verifying of sampling methods. The total length of the crown was measured, divided into three vertical sections, and processed by section. In each section, crowns were separated into live branches > 2 centimeters in diameter, live branches < 2 centimeters, dead branches, open cones, closed cones, 1-year needles, 2-year needles, and needles > 2 years old. Green weights of each component in each section were recorded in the field; components then were subsampled in the laboratory for nutrient and moisture content determinations.

The total length of the bole was measured and marked at 0.5-meter intervals; diameters outside bark and bark thickness were measured at each interval with calipers and a bark thickness gauge, respectively. The intact bole then was weighed with a Gravelle's gantry scale. Disks were removed at 2 meters and from the cut face of the stump for density and moisture analysis of wood and bark.

Five pairs of disks were taken, one for bolewood analysis (separation into bark, sapwood, heartwood) and one for nutrient concentration determination. These pairs were collected from the cut face, and at points one-fifth, two-fifths, three-fifths, and four-fifths of the way up the length of the bole and sealed in plastic bags. Green and dry weight and volume were measured from these disks in the laboratory. All roots within a 1-meter radius of the stump were extracted manually, washed, and separated into size classes. All were weighed in the laboratory, then subsampled for moisture content and nutrient analysis.

Nine fixed plots of 4 square meters each were established to inventory large woody debris (>2 centimeters in diameter), dead shrubs, live shrubs, grasses, and forbs in each 0.5-hectare sampling unit. Plants were clipped at ground level; all residue and woody debris in the fixed plots were collected. All materials were weighed, subsampled, and chipped for nutrient and moisture content. Soil pits were made by using a backhoe. Four pits were dug to a depth of 0.5 meter below the effective rooting depth or 0.5 meter into the buried soil, whichever was deeper. Soil sampling was done with an open-ended 0.25- by 0.25-meter frame, by horizon. Bulk density was sampled by displacement procedures described by Flint and Childs (1984). Soil samples for nutrients and bulk density were taken in the middle of each horizon. Soils were sieved with a 2-millimeter mesh sieve and subsampled for nutrient analysis.

Roots not passing through the sieve were bagged according to horizon sample and sent to the laboratory for nutrient and moisture analysis.

Forest floor material was excavated from within the 0.25- by 0.25-meter frame, bagged and weighed, and transported to the laboratory for further processing.

Laboratory Procedures

Plant and soil samples were oven dried at 103 °C for 48 hours to determine dry weight. Plant and soil materials to be analyzed for nutrients were air dried and then chipped, if not done so in the field.

All bole disk samples marked for density and moisture determination were weighed, then submerged and weighed for density determinations by using procedures of Heinrich and Lassen (1970). Disks were then dried and weighed for dry weight. Disks marked for bole component analysis were dissected into their sapwood, bark, and heartwood constituents, and each component weighed. Materials were ground to pass through a 20-mesh screen, and 50-gram samples were sent for nutrient analysis.

Crown material, shrubs, residue, herbs, and large roots were weighed and air dried. Materials (except needles) were chipped and divided into subsamples: one sample (50 grams) was oven dried then weighed again to determine moisture content; one sample was milled and sent for nutrient analysis (100-gram sample).

Root material taken within the soil profile was washed in distilled water, air dried, weighed, chipped, and subsampled for moisture content and chemical analysis. As with all other material, roots were ground to pass a 20-mesh screen, and 100-gram samples sent for chemical analysis.

All samples used for chemical analyses were air dried for 2 weeks and ground to pass a 20-mesh screen. Chemical analyses were conducted by the Oregon State University Department of Forest Science. Nitrogen (N) and phosphorus (P) samples were digested by the micro-Kjeldahl method (350 ^{o}C, K_2SO_4, $CuSO_4$, and Se as catalysts) and analyzed with a Scientific Instrument Continuous Flow Analyzer 200.[1] Soil sulfur was analyzed by a Perkin-Elmer 4000 Atomic Absorption Spectrophotometer. Plant sulfur was analyzed by the turbidity method described by Tabatabai (1970). Carbon was determined with a Leco induction furnace.

Statistical Analyses

The development of allometric equations is based on the assumption that there are constant and predictable relations between plant dimensions. Most researchers use easily measured dimensions, such as d.b.h. (1.3 meters above ground level) and tree height, as independent variables for predicting biomass of tree boles, foliage, and roots (Whitaker and Woodwell 1968). Biomass equations were developed by using linear regression analysis. A linear form of the allometric equation,

$$\ln Y = a + b (\ln X) , \tag{1}$$

was chosen because logarithmic transformations of both the dependent and independent variables corrected for the lack of homogeneity in variable variances. This model form is also consistent with previous work (Gholtz and others 1979, Shainsky and others 1992, Snell and Little 1983).

Dependent (Y) variables included dry weights of the total tree, bolewood, bark, crown, stump, and coarse roots. Independent (X) variables tested in one set of analyses were d.b.h. and total tree height; and the product of d.b.h. and total tree height (D^2H) was used as independent variables to generate another class of equations. All statistical analyses were performed by using SAS (1985).

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[1] The use of trade or firm names in this publication is for reader information only and does not imply endorsement by the U.S. Department of Agriculture of any product or servcie.

Site differences in allometrics were tested under the following model:

$$\ln Y = a + b_d(\ln D) + b_h(\ln H) + b_s(S) + b_{sd}(\ln D)(S) + b_{sh}(\ln H)(S) , \qquad (2)$$

where b_d is the regression coefficient for the relationship between lnY and d.b.h., b_h is the regression coefficient for the relationship between lnY and d.b.h., S is a site indicator variable from 1 to 6 (unique for each site), b_s is the regression coefficient that tests the significance of a site effect on the intercept of the relationship between lnY and lnD and lnH, b_{sd} is the regression coefficient that tests the significance of a site effect on the relationship between lnY and d.b.h., and b_{sh} is the regression coefficient that tests the significance of a site effect on the relationship between lnY and H. A coefficient was considered significant if its p-value was < 0.05. Site differences in nutrient concentrations were analyzed by using standard ANOVA procedures and tested using the Student's t-test statistic (Steel and Torrie 1980).

Results

Sampled Tree Population Characteristics

Tree characteristics across all six sites are presented in table 1. Tree density ranged from 278 trees per hectare at Bend 1 to 650 trees per hectare at Bend 2. Statistics for tree heights and diameters overlapped across sites. No one site had significantly larger trees than all the others, though Fort Rock 2 tended to have the shortest trees, and Sisters 2 the tallest trees. Fort Rock 2 exhibited the least amount of variation in size (standard deviation, table 1), and Bend 2 exhibited the greatest variation.

Biomass Equations

Although biomass allocation of individual trees tended to shift from boles to crown as we moved from Sisters to Fort Rock (moderate to harsh environments), no statistically significant differences in allometric relationships among sites were detected. Lack of significance in the analysis for heterogeneity of slopes (tested using equation 2, above) for biomass equations predicting tree biomass components from d.b.h. and height supported the pooling of observations from all sites to produce the equations presented in table 2. Logarithmic functions with the composite variable D^2H predicted biomass components just as well as functions using d.b.h. and height as separate independent variables, as indicated by the R^2 for the two different equations (table 2) and by the random distribution of residuals obtained from both sets of equations.

Coefficients of determination for equations predicting component dry weights were greater than 0.90 in all cases except for root dry weight, which had R^2's of 0.61 and 0.59. Although total tree height was a significant variable in the biomass equations, partial R^2 indicated that in most cases height only explained 1 to 5 percent of the total variation in dry weight of the different tree components.

Dry Weights of Ecosystem Components

Dry weights of the various components of second-growth ponderosa pine ecosystems are presented in table 3 for the three sites sampled for all components. In all cases, the soil represented the component of greatest mass, and the shrubs represented the least massive ecosystem component. Great variation in the mass of woody debris was observed (table 3). Ranges reported here may provide some useful boundaries for simulations using this data set to predict ecosystem budgets.

Nutrient Concentrations

Carbon concentrations in the trees, shrubs, area roots, forest floor, and residue ranged primarily from 45 to 55 percent; carbon concentrations in the soil were 4 percent or less (table 4). Few significant differences were detected among sites for the component concentrations. No clear pattern was evident across sites in the tree component nutrient concentrations. Concentrations of carbon in the soil tended to decrease in the order, Bend 2 > Fort Rock 1 > Fort Rock 2 (table 4).

Table 2—Equations for predicting biomass components of ponderosa pine from diameter at breast height and total height[a]

Biomass component	Equations	Coefficient of determination for the regression equation (R^2)	Sample size
Crown dryweight	$= \exp\{9.336 + 2.879*(\mathrm{LnDBH}) - 0.583*(\mathrm{LnHT})\}$	0.92	90
	$= \exp\{3.883 + 0.826*(\mathrm{LnD^2H})\}$	.86	
Bole dryweight	$= \exp\{3.857 + 1.601*(\mathrm{LnDBH}) + 1.183*(\mathrm{LnHT})\}$	.99	90
	$= \exp\{4.890 + 0.916*(\mathrm{LnD^2H})\}$	.99	
Bark dryweight	$= \exp\{2.664 + 1.611*(\mathrm{LnDBH}) + 1.047*(\mathrm{LnHT})\}$	.96	90
	$= \exp\{3.297 + 0.879*(\mathrm{LnD^2H})\}$	.96	
Total aboveground dry weight	$= \exp\{5.238 + 0.892*(\mathrm{LnD^2H})\}$	.98	90
	$= \exp\{5.940 + 1.942*(\mathrm{LnDBH}) + 0.711*(\mathrm{LnHT})\}$	.96	
Root dry weight	$= \exp\{5.491 + 2.308*(\mathrm{LnDBH})\}$	.61	27
	$= \exp\{2.459 + 0.792*(\mathrm{LnD^2H})\}$	.59	
Stump dry weight	$= \exp\{3.154 + 1.453*(\mathrm{LnDBH}) + 0.875*(\mathrm{LnHT})\}$	.93	27
	$= \exp\{3.544 + 0.773*(\mathrm{LnD^2H})\}$	.93	
Total dry weight	$= \exp\{6.578 + 2.059*(\mathrm{LnDBH}) + 0.618*(\mathrm{LnHT})\}$	.99	27
	$= \exp\{5.498 + 0.901*(\mathrm{LnD^2H})\}$	.99	

[a] Equations include trees from all sites, because site indices never entered any biomass equations as significant variables. All parameter estimates are significantly different from 0 at the 95-percent level of confidence.

Nitrogen concentrations were highest in the shrub component of all sites (table 5). Of the tree components, crowns and bark had the highest N-concentrations. Soil N-concentrations were 0.11 percent or lower and, on average, comprised the lowest N-concentrations of the sampled ecosystem components. No clear pattern across sites was discernible for N-concentrations in any of the nonsoil components. As with carbon, soil N-concentrations tended to decrease in the order, Bend > Fort Rock 1 > Fort Rock 2 (table 5).

As with N, P was highest in concentration in tree crowns, compared to all other tree components (table 6). Unlike the other elements, however, P-concentrations generally were highest in the soil (table 6). Phosphorus concentrations in the shrub component were almost as high as those in the soil. Of the tree components, the crown had the highest P-concentrations. Like the other elemental concentrations, no consistent site differences were evident in the tree component. As with carbon (C), soil P-concentrations tended to decrease in the order, Bend 2 > Fort Rock 1 > Fort Rock 2 (table 6).

Table 3—Average, standard deviation, and range of measured biomass components in 3 sites in ponderosa pine ecosystems in south-central Oregon on pumice soils

Site and component	Sample size	Mean	Standard deviation	Range	
				Minimum	Maximum
Bend 2:					
Shrubs (kg/ha)	10	14 347.6	12 090	352	41 264
Area roots (t/ha)	4	24.3	8	16	35
Forest floor (t/ha)	4	16.1	4	11	22
Residue (t/ha)	10	69.1	40	21	129
Soil profile (t/ha)—					
Horizon 1	4	774.6	271	421	1010
Horizon 2	4	1715.8	973	1088	3165
Horizon 3	4	2678.0	1635	1085	4931
Horizon 4	4	3983.2	2080	2203	6883
Horizon 5	2	4846.0	516	4481	5211
Fort Rock 1:					
Shrubs (kg/ha)	10	12 786.2	3176	9355	18 402
Area roots (t/ha)	4	18.6	6	15	27
Forest floor (t/ha)	4	34.4	15	12	45
Residue (t/ha)	10	21.2	15	4	53
Soil profile (t/ha)—					
Horizon 1	4	440.4	317	253	915
Horizon 2	4	1317.2	737	672	2308
Horizon 3	4	3106.9	1185	1624	4491
Horizon 4	4	2721.0	1161	1418	4160
Horizon 5	3	2574.7	1427	1155	4008
Fort Rock 2:					
Shrubs (kg/ha)	10	3969.8	5928	0	18 669
Area roots (t/ha)	4	24.6	3	22	29
Forest floor (t/ha)	4	12.0	5	6	17
Residue (t/ha)	10	290.2	435	14	1504
Soil profile (t/ha)—					
Horizon 1	4	480.6	167	262	659
Horizon 2	4	2470.9	1623	1085	4793
Horizon 3	4	2908.0	629	2214	3742
Horizon 4	4	4884.1	4495	787	9883
Horizon 5	2	9376.0	819	8797	9955

Text continues on page 11

Table 4—Carbon concentrations of ecosystem components on 3 Oregon sites

Sample	Bend	Fort Rock 1	Fort Rock 2
		Percent by weight	
Tree components:			
Crown	52.29[a]	51.82[b]	52.49[a]
Bolewood	50.69[a]	50.36[a]	50.55[a]
Bark	53.82[a]	53.08[b]	53.19[b]
Roots	51.96[a]	50.17[a]	50.79[ab]
Stump	52.79[a]	50.17[b]	51.39[ab]
Other:			
Shrubs	51.20[a]	43.50[a]	51.12[a]
Area roots	51.58[a]	49.66[b]	51.08[ab]
Forest floor	49.72[a]	46.98[a]	48.24[a]
Residue	50.22[a]	50.85[a]	51.11[a]
Soil horizons:			
Horizon 1	3.0716	3.87	3.94
Horizon 2	1.0385	.99	.81
Horizon 3	.6079	.52	.33
Horizon 4	.3930	.26	.25
Horizon 5	.2530	.26	.23
Soil average	*a*	*b*	*c*

[a, b, c] Values in a row having the same letter are not significantly different from one another. Because of varying sample sizes for some of the deeper soil horizons, t-tests were most valid for soil averages.

Table 5—Nitrogen concentrations of ecosystem components on 3 Oregon sites

Ecosystem component	Bend	Fort Rock 1	Fort Rock 2
		Percent by weight	
Tree components:			
Crown	0.41[a]	0.33[b]	0.47[b]
Bolewood	.08[a]	.07[a]	.09[a]
Bark	.17[a]	.15[b]	.16[b]
Roots	.10[a]	.09[a]	.08[a]
Stump	.06[a]	.05[a]	.06[a]
Other:			
Shrubs	.72[a]	.73[a]	1.24[b]
Area roots	.32[a]	.29[a]	.28[a]
Forest floor	.95[a]	.95[a]	.81[a]
Residue	.18[a]	.23[a]	.16[a]
Soil horizons:			
Horizon 1	.11	.12	.11
Horizon 2	.05	.04	.03
Horizon 3	.03	.02	.01
Horizon 4	.02	.01	.01
Horizon 5	.01	.02	.01
Soil average	*a*	*b*	*c*

[a, b, c] Values in a row having the same letter are not significantly different from one another. Because of varying sample sizes for some of the deeper soil horizons, t-tests were most valid for soil averages.

Table 6—Phosphorus concentrations of ecosystem components on 3 Oregon sites

Ecosystem component	Bend	Fort Rock 1	Fort Rock 2
		Percent by weight	
Tree components:			
Crown	0.05[a]	0.04[b]	0.068[c]
Bolewood	.01[a]	.01[a]	.01[a]
Bark	.03[a]	.03[a]	.03[a]
Roots	.03[a]	.02[a]	.03[a]
Stump	.01[a]	.01[a]	.01[a]
Other:			
Shrubs	.13[a]	.08[a]	.11[a]
Area roots	.08[a]	.08[a]	.06[b]
Forest floor	.08[a]	.08[a]	.07[a]
Residue	.01[a]	.01[a]	.01[a]
Soil horizons:			
Horizon 1	.14	.11	.08
Horizon 2	.10	.08	.06
Horizon 3	.07	.06	.04
Horizon 4	.06	.05	.03
Horizon 5	.06	.05	.02
Soil average	*a*	*b*	*c*

[a, b, c] Values in a row having the same letter are not significantly different from one another. Because of varying sample sizes for some of the deeper soil horizons, t-tests were most valid for soil averages.

Nutrient Budgets

The bolewood contained the greatest total amount of C of all the tree components (tables 5, 7, 8, and 9), and the soil contained the greatest stores of C of all measured ecosystem components. The three upper horizons at the Bend 2 and Fort Rock 1 sites had 68 and 76 percent, respectively, of the total C in the soil.

In contrast, a significant amount of C was observed in the deepest horizon at Fort Rock 2. The upper horizons of Bend and Fort Rock 1 soil tended to have the most N, but a substantial pool was observed in the deepest profile horizon of the Fort Rock 2 site. At the Fort Rock 1 site, the third horizon had the most P, and the fifth horizon of Fort Rock 2 and Bend 2 had the most P (tables 4, 8, and 9). Profile totals indicated that sampled ecosystem components stored about 58 to 78 megagrams/hectare of C, 2400 to 3650 kilograms/hectare N, and 6400 to 10 000 kilograms/hectare P at the specific time of measurement. It is important to consider that these are static estimates of dynamic pools.

Other Ecosystem Components

Of the other measured ecosystem components, the forest floor contained the most C, N, and P of the ecosystem components at the Fort Rock 1 site. At the Bend 2 site, residue contained the most C, the forest floor contained the most N, and shrubs the most P (table 7). At the Fort Rock 2 site, the residue contained the most C, N, and P. Despite their low total mass, shrubs contributed substantial N and P to the system (table 9).

Table 7—Nutrient content of the tree and other ecosystem components (mass/ha) estimated for the Bend 2 ecosystem in south-central Oregon on pumice soils[a]

Ecosystem component	Total weight of component	Nutrients		
		Carbon	Nitrogen	Phosphorus
	Tonne/hectare	*Million grams/hectare*	*– – Kilograms/hectare – –*	
Trees:				
Crown	30.1(0.28)	16.2(0.28)	126.3(0.67)	15.8(0.59)
Bolewood	60.6(0.54)	30.7(0.54)	48.2(0.26)	7.9(0.30)
Bark	10.9(0.10)	5.9(0.10)	18.7(0.10)	2.8(0.10)
Stump	13.5(0.12)	7.1(0.12)	8.3(0.04)	1.3(0.05)
Roots	6.6(0.06)	3.4(0.06)	6.3(0.03)	1.7(0.06)
Total	111.6	57.4	189.4	26.61
Soil profile:				
Horizon 1	774.6(0.06)	23.4(0.30)	885.5(0.24)	1117.5(0.11)
Horizon 2	1715.8(0.12)	15.8(0.19)	702.8(0.19)	1549.5(0.15)
Horizon	2678.0(0.19)	14.0(0.19)	737.4(0.20)	2010.0(0.20)
Horizon 4	3983.2(0.28)	12.3(0.16)	670.0(0.18)	2456.8(0.25)
Horizon 5	4845.0(0.35)	12.5(0.16)	653.4(0.18)	2866.9(0.29)
Horizons 1 + 2	2490.3(0.18)	38.5(0.49)	1588.2(0.43)	2667.0(0.26)
Total	13 997.5	78.2	3648.0	10 000.7
		Kilograms per hectare		
Other components:				
Residue	69.1(0.56)	34.6(0.60)	122.3(0.28)	8.3(15)
Forest floor	16.1(0.13)	8.0(0.14)	154.6(0.35)	12.0(0.24)
Fine roots	24.3(0.20)	7.9(0.14)	54.3(0.12)	14.8(0.27)
Shrubs	14.4(0.12)	7.3(0.13)	105.6(0.24)	18.2(0.34)
Total	123.8	57.8	436.8	54.2

[a] Percentage of total tree nutrients found in each tree component indicated in parentheses.

Text continues on page 15

Table 8—Nutrient content of the tree and other ecosystem components (mass/ha) estimated for the Fort Rock 1 ecosystem in south-central Oregon[a]

Ecosystem component	Total weight of component	Nutrients: Carbon	Nitrogen	Phosphorus
	Tonne/hectare	*Million grams/hectare*	*– – Kilograms/hectare – –*	
Trees:				
Crown	28.3(0.24)	14.7(0.25)	91.0(0.60)	11.4(0.51)
Bolewood	63.3(0.54)	31.0(0.54)	46.2(0.30)	7.0(0.36)
Bark	12.5(0.11)	6.7(0.11)	18.2(0.12)	3.1(0.14)
Stump	19.2(0.16)	9.7(0.16)	10.2(0.07)	1.6(0.07)
Roots	5.8(0.05)	2.9(0.05)	4.0(0.03)	1.4(0.06)
Total	116.6	59.1	153.3	22.4
Soil profile:				
Horizon 1	1440.4(0.04)	15.4(0.26)	456.5(0.19)	463.6(0.07)
Horizon 2	1317.9(0.13)	13.7(0.24)	530.1(0.22)	1134.5(0.18)
Horizon 3	3106.9(0.31)	15.5(0.26)	655.2(0.27)	1997.3(0.31)
Horizon 4	2720.0(0.27)	6.9(0.12)	377.1(0.16)	1416.6(0.22)
Horizon 5	2574.7(0.25)	6.0(0.12)	384.4(0.16)	1394.0(0.22)
Horizons 1 + 2	1758.3(0.17)	29.1(0.50)	986.5(0.41)	1598.2(0.25)
Total	10 160.8	58.5	2403.2	6407.0
		Kilograms per hectare		
Other components:				
Residue	21.2(0.24)	10.8(0.26)	39.7(0.08)	2.6(0.05)
Forest floor	34.4(0.40)	16.5(0.40)	329.3(0.65)	28.1(0.52)
Fine roots	18.6(0.21)	8.0(0.20)	42.4(0.08)	12.6(0.23)
Shrubs	12.9(0.15)	5.8(0.14)	97.1(0.19)	10.5(0.20)
Total	87.1	41.1	508.5	53.9

[a] Percentage of total tree nutrients found in each tree component indicated in parentheses.

Table 9—Nutrient content of the tree and other ecosystem components (mass/ha) estimated for the Fort Rock 2 ecosystem in south-central Oregon[a]

Ecosystem component	Total weight of component	Nutrients: Carbon	Nitrogen	Phosphorus
	Tonne/hectare	*Million grams/hectare*	*– – Kilograms/hectare – –*	
Trees:				
Crown	18.7(0.32)	9.8(0.33)	87.0(0.73)	10.9(0.65)
Bolewood	28.1(0.48)	14.2(0.47)	24.2(0.20)	3.7(0.22)
Bark	5.9(0.10)	3.2(0.10)	9.3(0.08)	1.6(0.10)
Stump	7.6(0.13)	3.9(0.13)	4.3(0.04)	.9(0.05)
Roots	4.3(0.07)	2.2(0.07)	3.5(0.03)	1.2(0.07)
Total	58.7	30.1	119.9	16.7
Soil profile:				
Horizon 1	480.6(0.02)	15.4(0.20)	437.9(0.17)	386.3(0.06)
Horizon 2	2470.9(0.12)	19.8(0.26)	664.6(0.25)	1494.8(0.23)
Horizon 3	2908.3(0.14)	9.7(0.13)	367.7(0.14)	1223.3(0.19)
Horizon 4	4884.1(0.24)	8.8(0.12)	433.7(0.16)	1205.7(0.19)
Horizon 5	9375.7(0.47)	21.0(0.29)	729.2(0.28)	2142.0(0.33)
Horizons 1 + 2	2951.6(0.14)	35.1(0.47)	1102.5(0.42)	1881.0(0.29)
Total	20 119.6	75.0	2633.2	6452.1
		Kilograms per hectare		
Other components:				
Residue	290.2(0.88)	153.6(0.89)	353.7(0.64)	25.2(0.50)
Forest floor	12.0(0.04)	5.8(0.03)	93.7(0.17)	7.6(0.15)
Fine roots	24.67(0.07)	11.4(0.07)	62.4(0.11)	12.6(0.25)
Shrubs	3.0(0.01)	2.1(0.01)	46.2(0.08)	4.5(0.09)
Total	330.0	172.9	556.1	49.9

[a] Percentage of total tree nutrients found in each tree component indicated in parentheses.

Table 10—Percent of total nutrient captial represented by each ecosystem component

Site and component	Carbon	Nitrogen	Phosphorous	Sulfur
		Percent		
Bend 2:				
Trees (total)	30	4	.26	1.45
Soil profile	40	85	98.20	95.78
Residue	18	3	.08	1.00
Forest floor	4	4	.13	1.06
Area roots	4	1	.15	.37
Shrubs	4	2	.18	.34
Fort Rock 1:				
Trees (total)	37	5	.34	1.86
Soil profile	37	78	98.82	93.58
Residue	7	1	.04	.35
Forest floor	10	11	.43	3.18
Area roots	5	1	.19	.59
Shrubs	4	3	.16	.44
Fort Rock 2:				
Trees (total)	11	4	.26	1.29
Soil profile	27	80	98.98	92.58
Residue	55	11	.39	3.71
Forest floor	2	3	.12	.78
Area roots	4	2	.19	1.41
Shrubs	1	1	.07	.23

Percentage of Ecosystem Total Contributed by Component

Table 10 provides the percentages represented by each component for all three sites. In all cases, the soil contributed more than 78 percent of the N to an ecosystem and more than 98 percent of the P.

The trees contributed most to the carbon pool and, compared to the soil, stored little of the system's N and P. Disregarding the soil's massive nutrient pools, the trees and the forest floor tended to have the most N and P in the other system components, except at the Fort Rock 2 site, where residue appeared to contribute more to the nutrient pools. Residue on the Fort Rock 2 site was extremely patchy, such that when one sample fell onto a debris pile, the estimate for the site average was inflated and thus the total weight of nutrients calculated for residue for that site.

Discussion

From the ranges in biomass determined directly and predicted from equations in table 2, a budget for C, N, P, and dry matter can be developed to determine potential nutrient and biomass removal resulting from intermediate harvests in second-growth ponderosa pine. The figures reported here represent only estimates but were derived from the most comprehensive survey of its kind in second-growth ponderosa pine. These estimates may be used for product allocation models applicable to the ponderosa pine resource. The coefficients that predict tree biomass components from height and diameter are fairly robust.

No statistically significant trends were detected in biomass allocation when we compared sites, which suggests that these coefficients may be useful over a wide range of the ponderosa pine populations in central and eastern Oregon. The lack of the significance of site differences in coefficients allowed us to combine data from all sites to produce equations having greater degrees of freedom than many of those previously published for ponderosa pine.

These equations may be applied to stand table information for east-side second-growth ponderosa pine trees in the range of tree sizes represented by our sample (table 1). These coefficients are from logarithmic equations and were not adjusted for bias (Baskerville 1972).

The ranges of dry weights of different ecosystem components presented in table 3 provide some boundaries for simulations that predict ecosystem budgets. In many cases, the coefficient of variation is quite high. In particular, great variation in the mass of woody debris was observed both within and among sites (table 3). These numbers reflect the patchy nature of downed material in most forest ecosystems. Researchers and managers using these estimates as rough guidelines should sample the residue on a particular site, because this is one of the ecosystem components that seems to differ the most in quantity.

As with most studies, crown nutrient concentrations were generally the highest of all tree components. This finding provides support for the general practice of bole-only harvesting, and suggests that leaving the crown material on site might mitigate some potential nutrient-related impacts of tree removal on site productivity. Because the bark also retains a fairly high nutrient content, on-site debarking of trees may be another route for reducing nutrient export.

Fairly high nutrient concentrations were observed in the shrub component (table 4), but because of their low mass, total contribution by shrubs to the nutrient budget was minor. Though it is tempting to suggest that control of the shrub component might free up some of nutrients for the trees, shrubs play a key role in the nutrient cycling process.

Nutrient concentrations in the soil were low relative to most other ecosystem components measured. The great mass of the soil made estimates of total nutrient content in the soil rather high in comparison with all other ecosystem components, however. As a consequence, it seems as if removal of the above-ground tree component has little impact on the total ecosystem nutrient pool. The soil nutrient pools reported here are totals and do not necessarily reflect the nutrient contents available to the trees. They are static estimates of dynamic pools, because concentrations were sampled only once during the summer months. Thus, it is important to look closely at the absolute amount of nutrients leaving the site when considering potential impacts, and to sample more frequently to calculate temporal changes in nutrient pools.

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We investigated the distribution of biomass and nutrients in second-growth ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) ecosystems in central Oregon. Destructive sampling of aboveground and belowground tree biomass was carried out at six sites in the Deschutes National Forest; three of these sites also were intensively sampled for biomass and nutrient concentrations of the soil, forest floor, residue, and shrub components. Tree biomass equations were developed that related component biomass to diameter at breast height and total tree height.

Keywords: Biomass, nutrient concentrations, allometric equations, ponderosa pine, carbon storage.

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